$\mathbf{K_L \to \pi^+\pi^-\pi^0 e^+ e^-}$ and $\mathbf{K_L \to \pi^0\pi^0\pi^0 e^+ e^-}$

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Overview

- What is $\pi\pi\pi ee$? Introduction.
  - Theory
  - Existing experimental results
  - Motivation for $\pi\pi\pi ee$ search
- Search for $K_L \to \pi^+\pi^-\pi^0 e^+ e^-$
  - Simple analysis of 0.6% of KTeV data.
  - First observation of the decay
  - Prospects for serious analysis of entire KTeV data
- Search for $K_L \to \pi^0\pi^0\pi^0 e^+ e^-$
  - Simple analysis of $\sim$25% KTeV data.
  - Identifying main backgrounds
  - Prospects for serious analysis of entire KTeV data.

Theory and Existing Experimental results

- No published experimental results or predictions about $\pi\pi\pi ee$ decays.
- No published experimental results about $\pi\pi\pi\gamma$ decays
- $K_L \to \pi^+\pi^-\pi^0\gamma$ KTeV result (not published), '97 E832 data.
  - $\sim$2900 events
  - Measured BR=(1.70$\pm$0.06)$\times 10^{-4}$
  - Good agreement with theoretical predictions
- ChPT predictions for $K_L \to \pi^+\pi^-\pi^0 e^+e^-$ BR=(1.65$\pm$0.03)$\times 10^{-4}$, hep-ph/9612412
- $K_L \to \pi^+\pi^-\pi^0\gamma$ proceed via internal Brem (100%)
- May expect BR($K_L \to \pi^+\pi^-\pi^0 e^+e^-$)$\sim 10^{-6}$
  - easy measurement for KTeV
  - never been observed before

Contributions Other than Brem

- Very small in $\pi^+\pi^-\pi^0\gamma$
  - BR(DE)=$(8a_1+a_2-10a_3)^2\times 2\times 10^{-10}$, Nucl.Phys.B413, 321
    $3a_2-6a_3-2=-4.5\pm 0.5$
  - BR(DE)$>1.6\times 10^{-10}$
    My estimations from numbers in hep-ph/9612412
- Additional amplitudes in $\pi\pi\pi\gamma^*$ may increase BR
- These contributions, *O(p^4) and O(p^6)*, is not easy to calculate in ChPT. Experimental results needed to test ChPT at this level.
- Compare $\pi^+\pi^-\pi^0\gamma$ and $\pi^+\pi^-\pi^0\gamma^*$ but Brem is too strong.
- Search for $\pi^0\pi^0\pi^0\gamma$ and $\pi^0\pi^0\pi^0\gamma^*$. No Brem there.

Expectations for $\pi^0\pi^0\pi^0\gamma^*$

No theoretical papers (= I could not find any). These are my speculations based on comparison with $\pi^0\pi^0 e^+e^-$

- $\pi^0\pi^0 e^+e^-$ is expected to have BR=2×10^{-10}
  - 1/3 of the rate due to DE(E2)
  - 2/3 of the rate due to "charged radius" $K_L \to \gamma^* K_S(K_S \to \pi^0\pi^0)$
- DE in $\pi^0\pi^0\gamma$ suppressed to E2 but may be boosted to E1 (or M1?) in $\pi^0\pi^0\pi^0\gamma$
- "Charged radius" amplitude is suppressed by CP violation:
  $K_L \to \gamma^* K_S(K_S \to \pi^0\pi^0\pi^0)$
  but other similar amplitudes may be present.
- Overall, the rate for $\pi^0\pi^0\pi^0\gamma^*$ most likely is very small.

Enough speculations, lets look at the data...

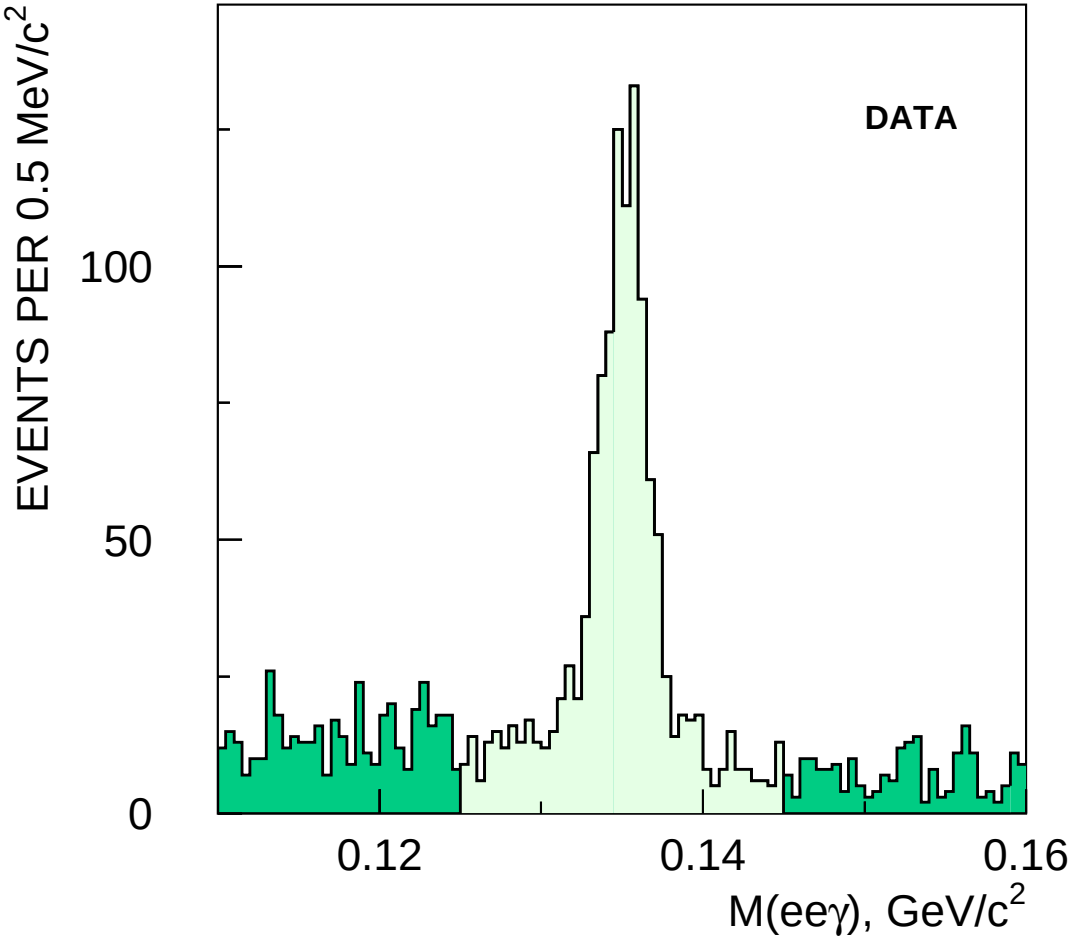
Search for $K_L \to \pi^+\pi^-\pi^0 e^+ e^-$ at KTeV

General Remarks:

- $\sim$180 tapes of 4TRK raw tapes from '97 and '99 runs need to be recrunched.
- 0.6% data analized according to normalization mode (details later)
- 20/20 analysis (not "blind" analysis)
  - Only small fraction of data is analized.
  - All cuts are based on previous knowelage about KTeV data.
  - If there is a bias, it will be detected on next chunk of data.

Event Selection

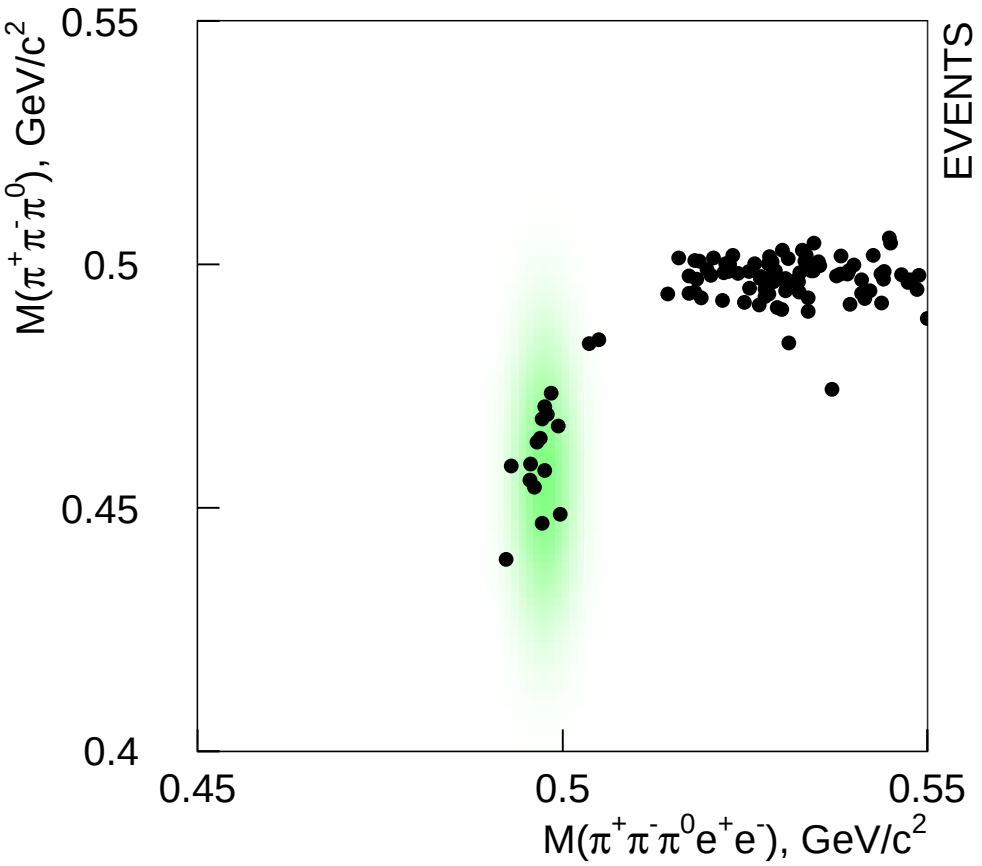
- 4TRK trigger
- 4 tracks, no Y sharing
- IPACK(1)=16399, IPACK(2)=2652
- 4-track vertex
- Track-Cluster match = 2
- $\pi^{\pm}$: E/p<0.9
- $e^{\pm}$: 0.9<E/p<1.1
- γ:
  - HW cluster
  - E>2 GeV
  - FUSE3X3CS<5.0
  - FUSECHI2CS<8.0
- M($\pi\pi ee$) < 0.4 GeV/c^2
- M($\gamma\gamma$)=M$_{\pi^0}$ $\pm$ 5 MeV/c^2

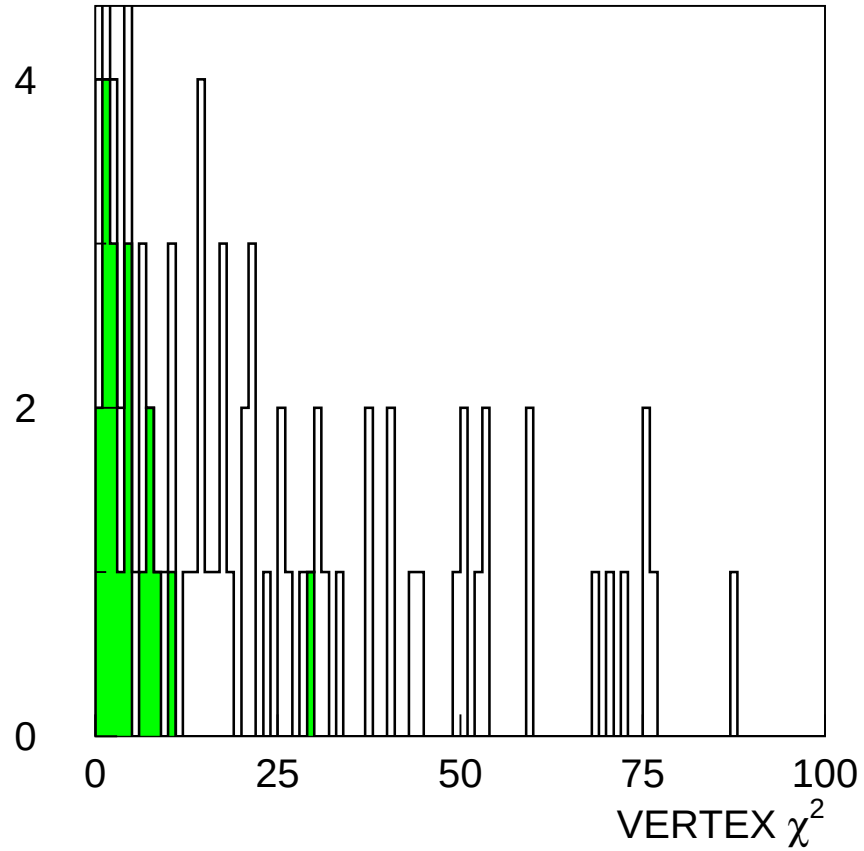


Background Cuts:

M($ee\gamma$) <> M$_{\pi^0}$ $\pm$ 10 MeV/c^2

M($ee\gamma\gamma$) <> M$_{\pi^0}$ $\pm$ 15 MeV/c^2

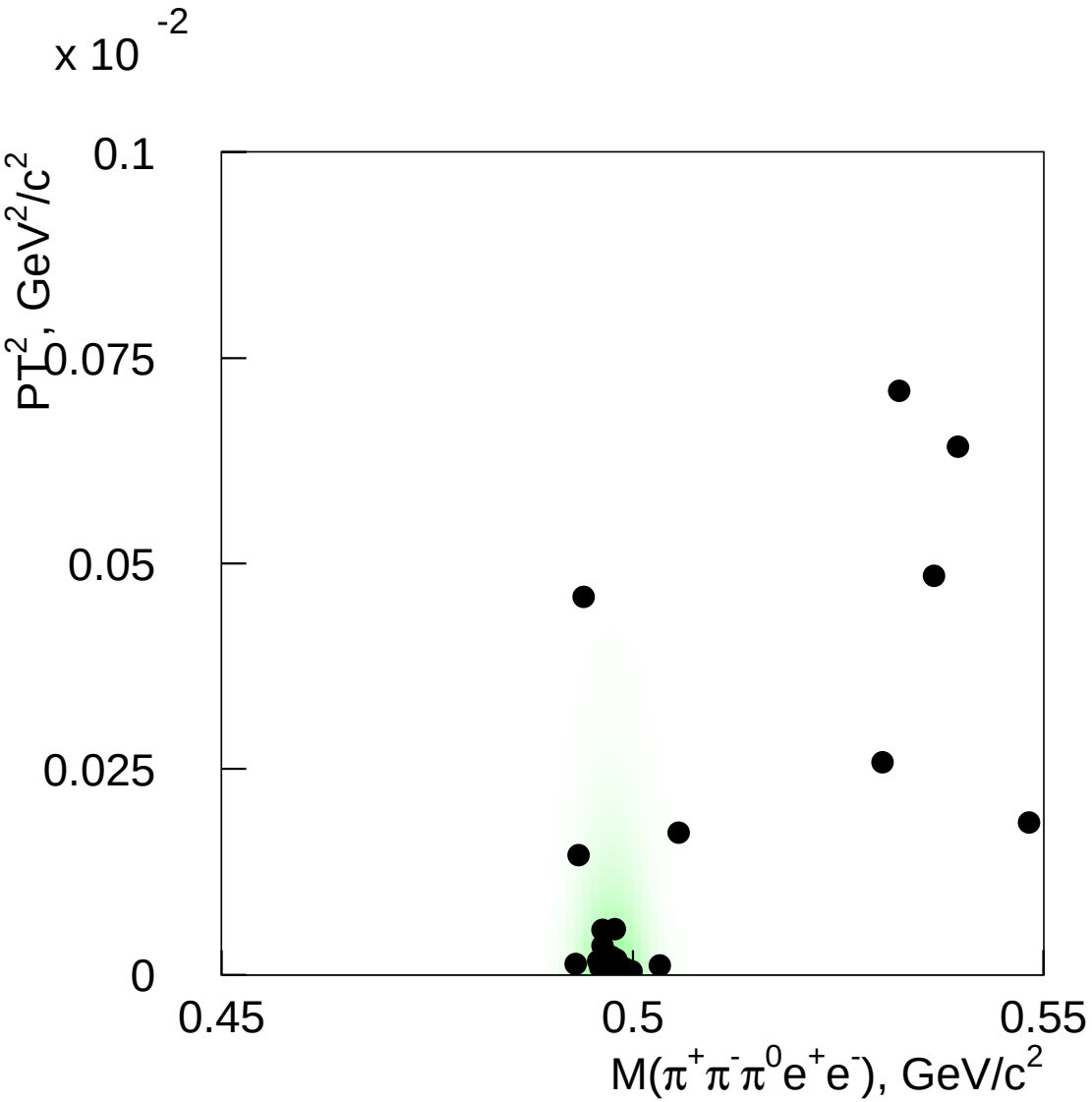




Remaining background:

- probably $K_L \to \pi^+\pi^-\pi^0$ $(\pi^0 \to \gamma\gamma)$
- away from signal region (shaded)
- poor vertex quality

First Observation of $K_L \to \pi^+\pi^-\pi^0 e^+ e^-$



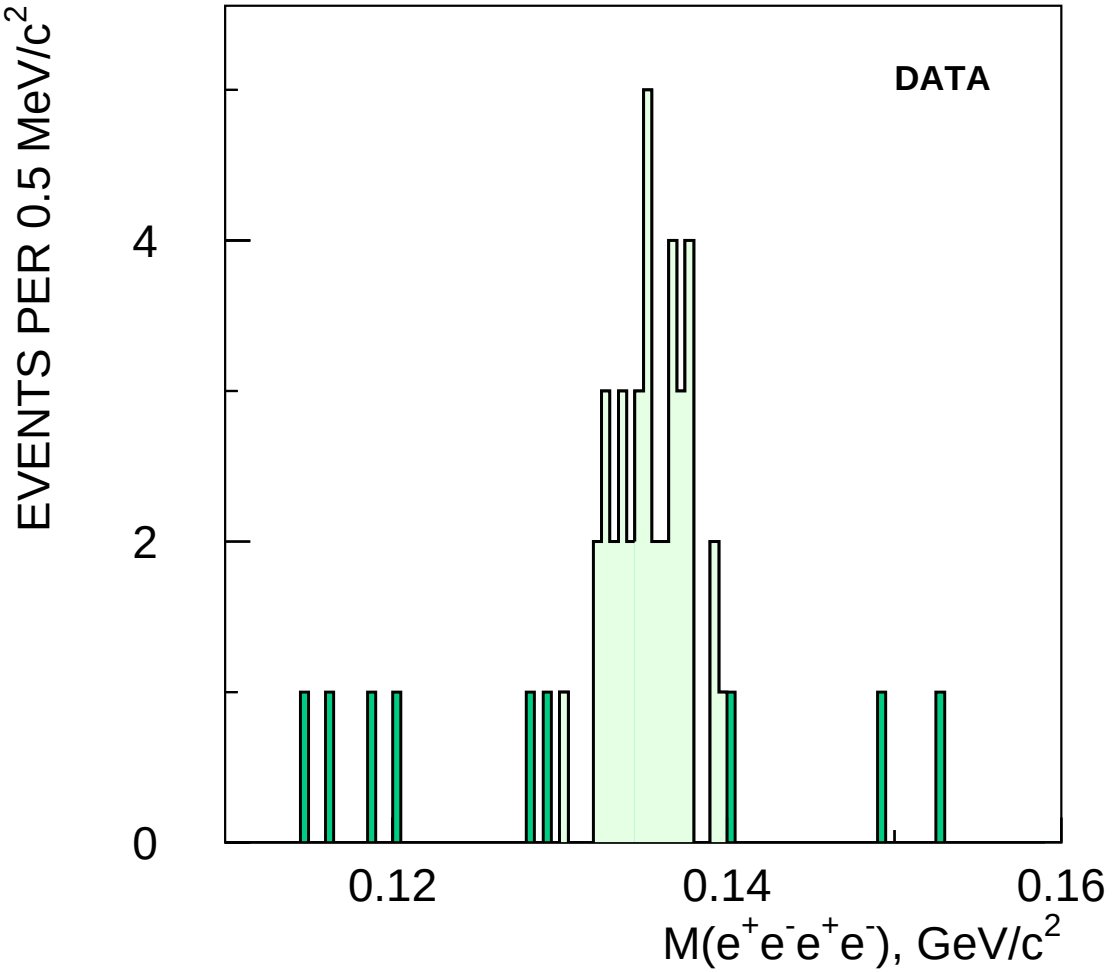
One more cut:

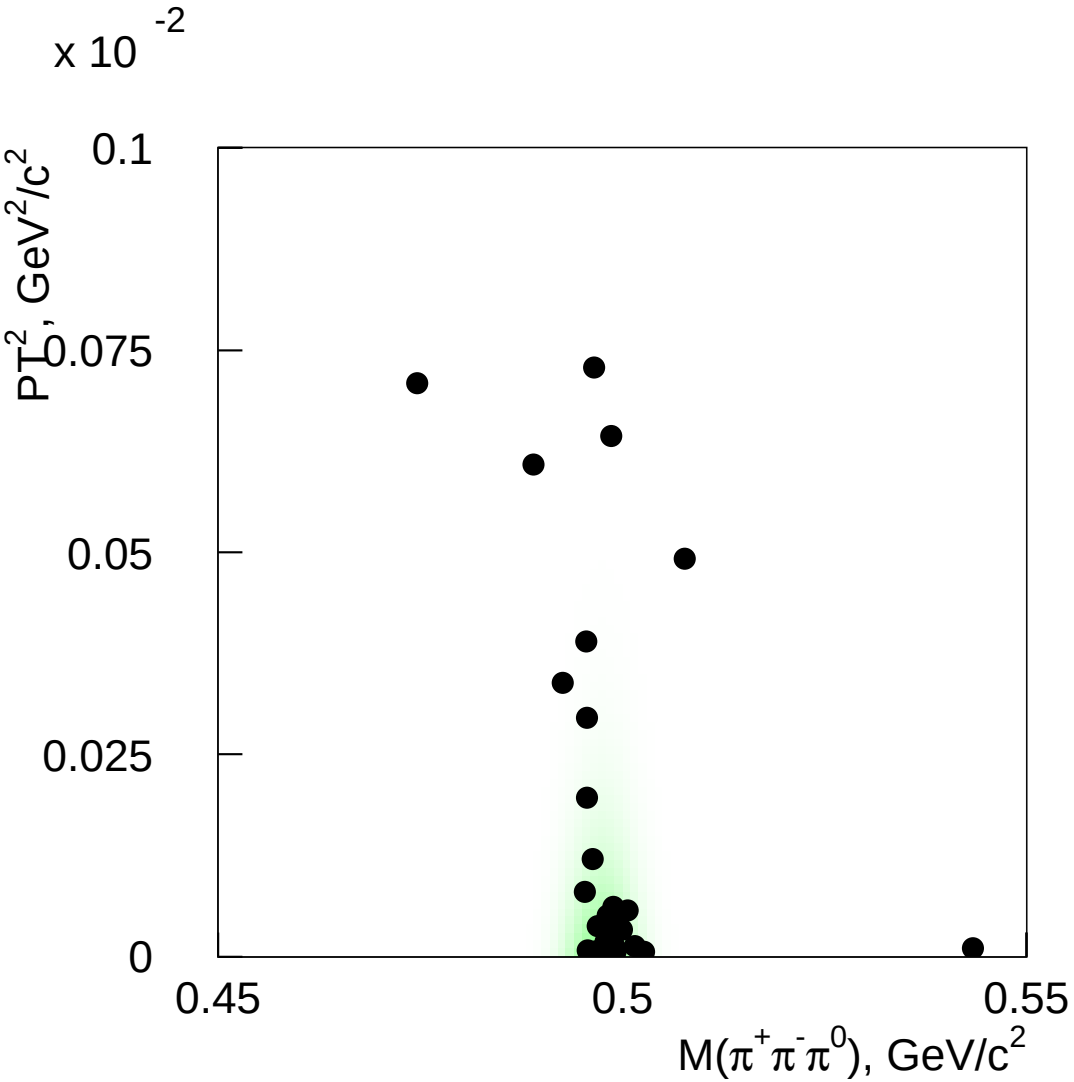
$M(\pi^+\pi^-\pi^0) < 0.490$ GeV/c^2

Observed 17 candidates

Normalization mode: $K_L \to \pi^+\pi^-\pi^0$ with $\pi^0 \to e^+e^-e^+e^-$

- Same trigger
- Same 4-track vertexing
- NTRK = 6
- Same number of π
- Same number of e/γ
- $M_{ee} > 5$ MeV/c^2
- $M_{eeee} = M_{\pi^0} \pm 5$ MeV/c^2





- Acceptance = 0.16%
- BR = 4×10^{-6}
- Obserevd 23 events
- Flux analized: 3.6×10^{9}
- Fraction of data: 0.6%

Summary of $K_L \to \pi^+\pi^-\pi^0 e^+e^-$

- 17 candidates from 0.6% of available data.
  First observation.
  Clean signal.
- Possible background from $K_L \to \pi^+\pi^-\pi^0\gamma$
- Expect 2000–3000 from entire data sample.
- Maybe enough to compare E_γ with $K_L \to \pi^+\pi^-\pi^0\gamma$
- Different normalization mode?
- Need to write Monte Carlo for this decay.
- Need to process $\sim$180 tapes of raw 4TRK data.
- Will be good addition to $K_L \to \pi^+\pi^-\pi^0\gamma$ KTeV result

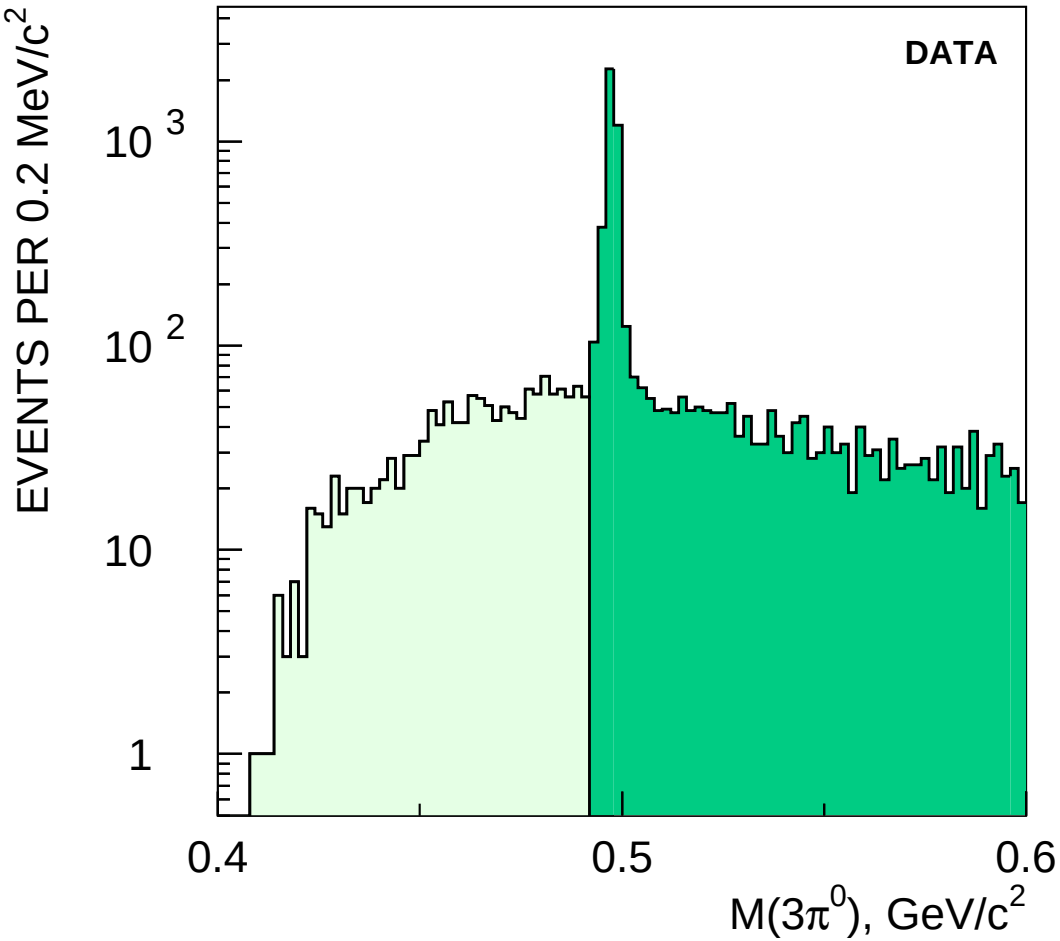
Search for $K_L \to \pi^0\pi^0\pi^0 e^+ e^-$ at KTeV

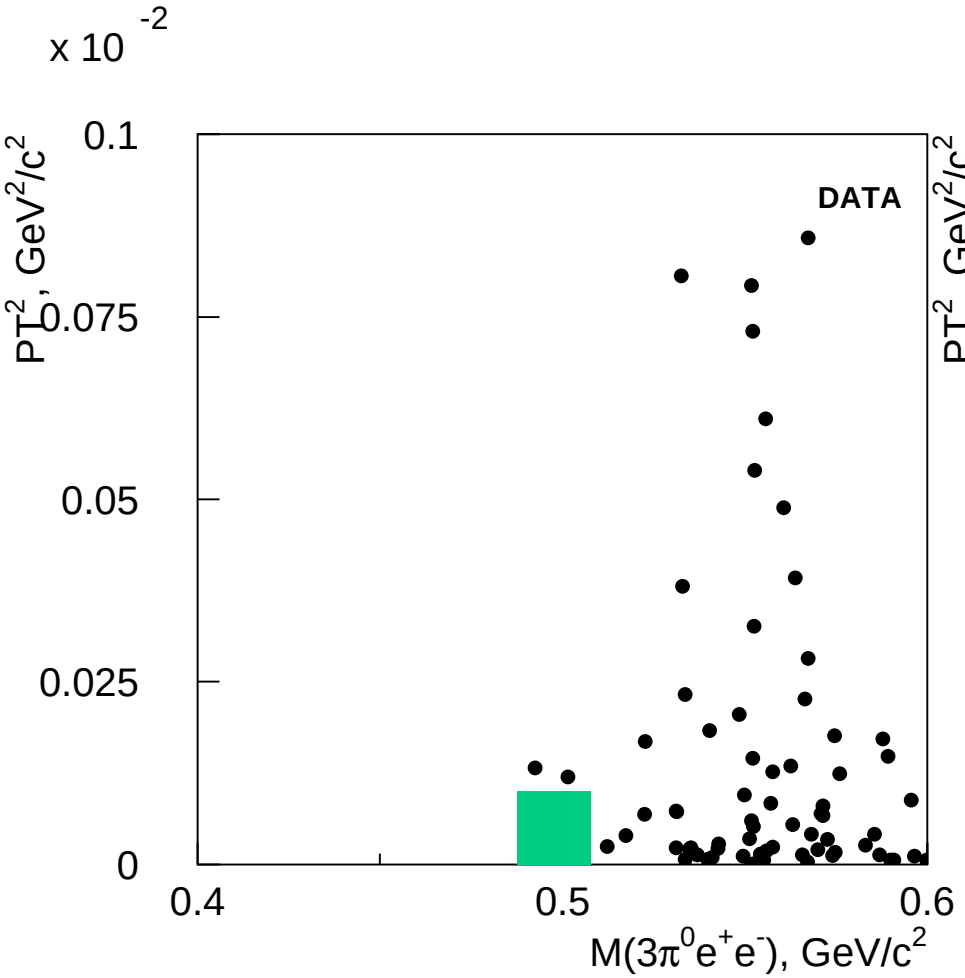
General Remarks:

- 2ENCLUS trigger.
- Crunch output with 2T8CL tag (2 track, NCLUS$\geq$8)
- The entire KTeV data = 4 DLT tapes, NQN601–NQN604
- Main background is expected from *multiple* K_L decays in vacuum region.
  - Background rate is a function of beam flux **and** beam intensity.
  - Need find a way to normalize MC simulations of the backgrounds
  - How to simulate double decays in KTEVMC ?
- “Blind” analysis probably is a way to go.
- Background rejection is not as easy as in $K_L \to \pi^+\pi^-\pi^0 e^+ e^-$

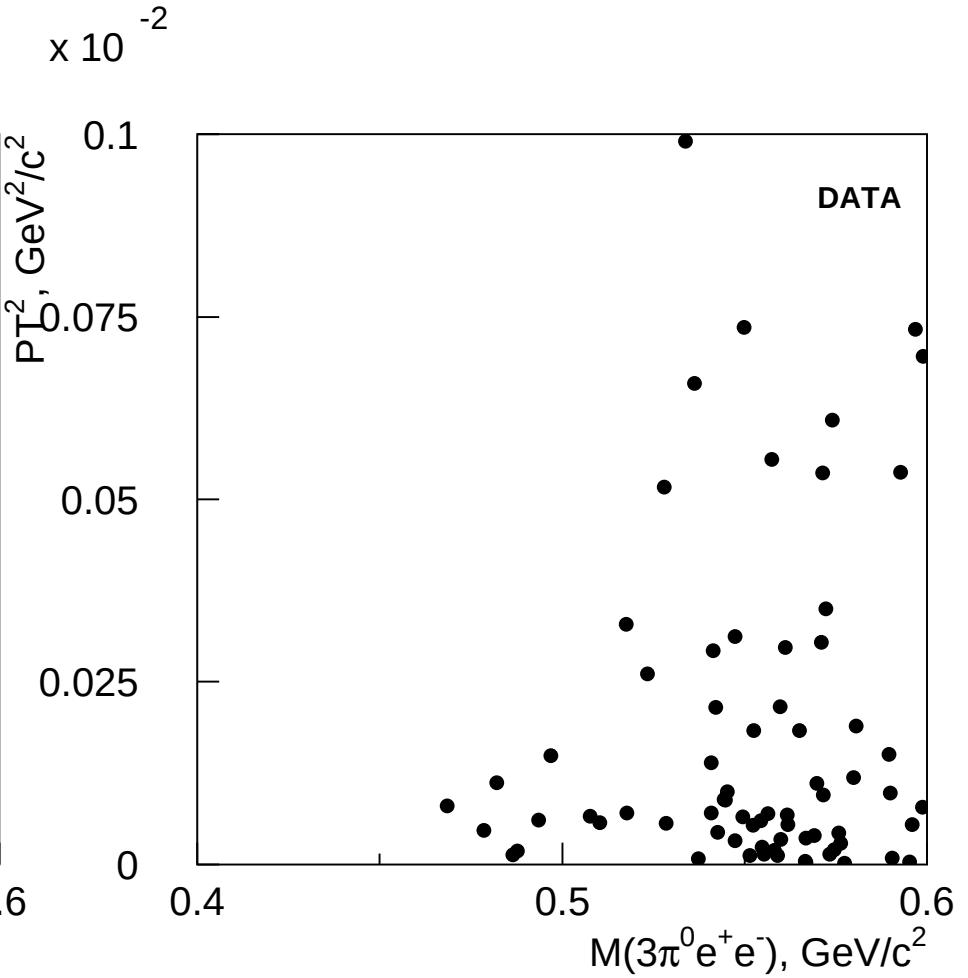
Event Selection

- NTRK=2, no Y sharing
- IPACK(1)=16399, IPACK(2)=2652
- Vertex, matching=3
- $e^{\pm}$: 0.9<E/p<1.0
- γ:
  - FUSECHI2CS<20.0
  - SEED block is not edge
- Find $3\pi^0$ vertex Z pos. X and Y of charged vertex
- $M(3\pi^0)<0.492$ GeV/c^2
- $(5<M(ee)<100)$ MeV/c^2



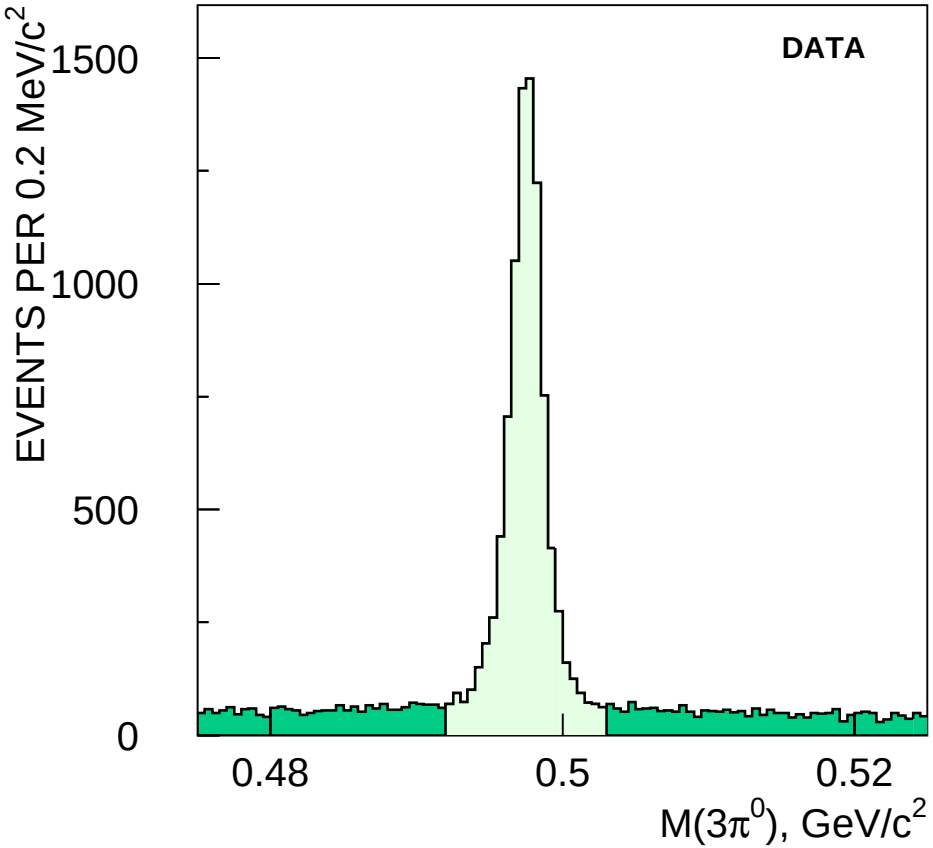


Good $3\pi^0e^+e^-$ Vertex



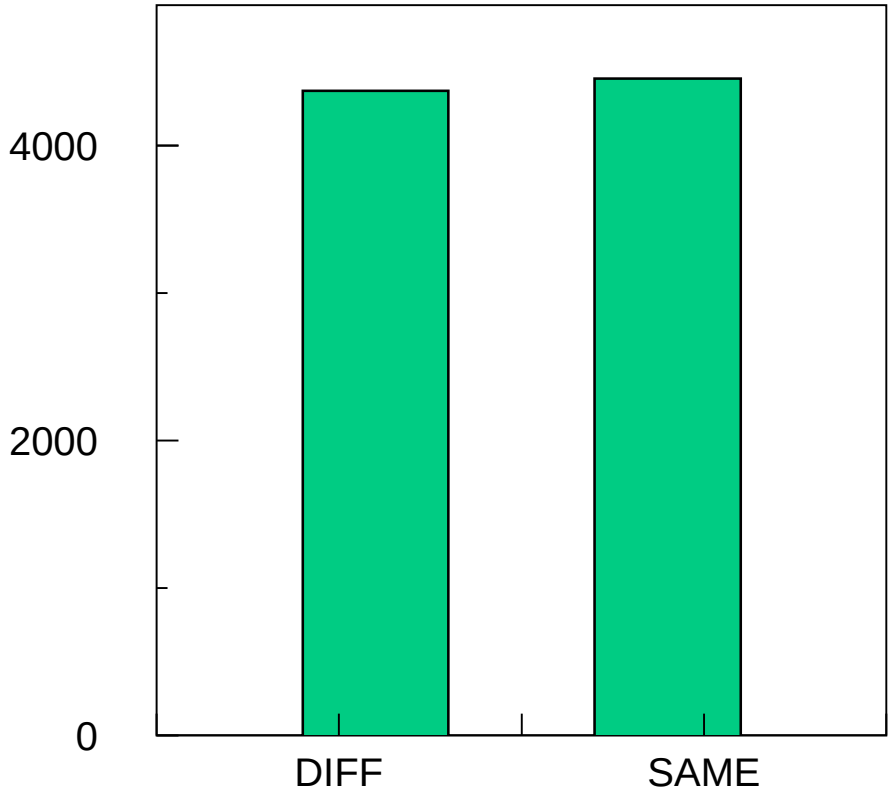
Bad $3\pi^0e^+e^-$ Vertex

Sources of Background



Reconstructed $K_L \to 3\pi^0(6\gamma)$

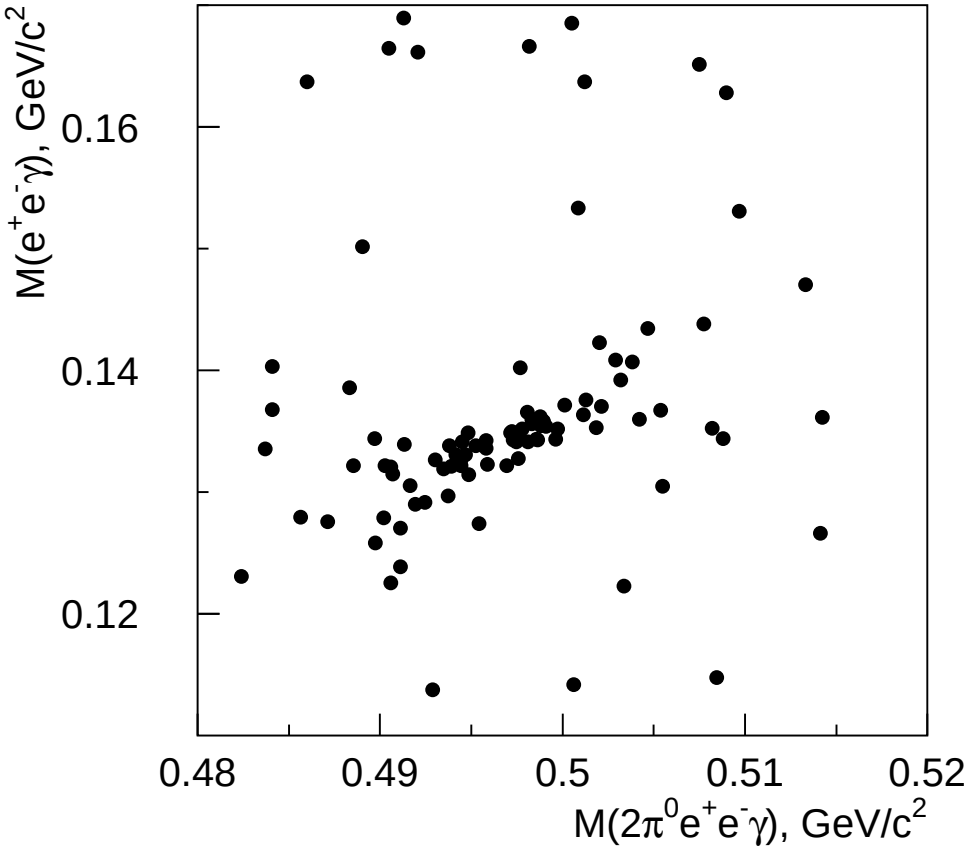
- $\sim$8800 events
- Mean = 497.52$\pm$0.02 MeV/c^2
- σ = 1.18$\pm$0.02 MeV/c^2



Charged and Neutral

- Same beam
- Opposite beam

Evidence of 2 independent decays



Events with 2 completely reconstructed decays

- $K_L \to 3\pi^0(6\gamma)$
- $K_L \to 3\pi^0_D$

The way to normalize MC simulation of double decays for background studies

Summary of $K_L \to \pi^0\pi^0\pi^0 e^+ e^-$

- 1 Tape (out of 4) is processed
- Most likely all backgrounds come from double decays
  - Can be simulated with MC
  - Can be studied with data
- Expect 0–few events
- Need to choose normalization mode?
- Need to write Monte Carlo for this decay.

Last word

Is there enough interest

to have

$$K_L \to \pi^+\pi^-\pi^0 e^+ e^-$$

and

$$K_L \to \pi^0\pi^0\pi^0 e^+ e^-$$

analyses finished?